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Quantitative appraisal and potential analysis for primary biomass resources for energy utilization in China

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ABSTRACT

As the largest agricultural country, China has abundant biomass resources, but the distribution is scattered and difficult to collect. It is essential to estimate the biomass resource and its potential for bioenergy utilization in China. In this study, the amount of main biomass resources for possible energy use and their energy utilization potential in China are analyzed based on statistical data. The results showed that the biomass resource for possible energy use amounted to 8.87×10^8 tce in 2007 of which the crops straw is 1.42×10^8 tce, the forest biomass is 2.85×10^8 tce, the poultry and livestock manure is 4.40×10^7 tce, the municipal solid waste is 1.35×10^6 tce, and the organic waste water is 6.46×10^6 tce. Through the information by thematic map, it is indicated that, except arctic-alpine areas and deserts, the biomass resource for possible energy use was presented a relatively average distribution in China, but large gap was existed in different regions in the concentration of biomass resources, with the characteristics of *East dense* and *West sparse*. It is indicated that the energy transformation efficiency of biomass compressing and shaping, biomass anaerobic fermentation and biomass gasification for heating have higher conversion efficiency. If all of the biomass resources for possible energy use are utilized by these three forms respectively, 7.66×10^{12} t of biomass briquettes fuel, 1.98×10^{12} m^3 of low calorific value gas and 3.84×10^{11} m^3 of biogas could be produced, 3.65×10^8 t to 4.90×10^8 t of coal consumption could be substituted, and 6.12×10^8 t to 7.53×10^8 t of CO_2 emissions could be reduced. With the enormous energy utilization potential of biomass resources and the prominent benefit of energy saving and emission reduction, it proves an effective way to adjust the energy consumption structure, to alleviate the energy crisis, to ensure the national energy security and to mitigate the global warming trend.

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1. Introduction

Efficient exploitation and cleaner utilization of biomass resources has been attracted more attention all around the worlds, with the increasing consumption of conventional energy, diminishing supplement of fossil energy, and also with environmental degenerating and climate changing [1,2]. The biomass is currently regarded as the most potential renewable energy source in that it is the only renewable carbon source and the only renewable energy that can be directly converted to liquid fuel, which can contribute to the world's sustainable energy supply in the future [3–5]. The biomass resource is abundant in China, and the theoretical reserve is about 5 billion tce, which is about two times as much as the present China's total energy consumption [6]. However, these resources overspread the whole country, and are difficult to be collected and stored. As the feedstock of large-scale energy development, quantitative analysis of the available amount of biomass resources for energy use is particularly important. Meanwhile, based on the present biomass conversion efficiency, to estimate the potential of biomass resources used for energy is also significant for bioenergy industry development planning. A number of researchers have focused on the potential of biomass resource [7–11], expecting to solve the energy crisis, rural nonpoint pollution and atmospheric pollution by straw burning. Mei et al. [7] have appraised the crops straw resource in Liaoning Province, and argued that utilization direction of crops straw for energy is compatible with many kinds of utilizing forms. Li and Wang [8] have analyzed the current situation and development prospects of crops straw used for energy in Inner Mongolia Autonomous Region. Wei and Lu [9] have pointed out that the annual production of biomass energy of agriculture and forestry in Hebei Province is more than 20 million tons. Yan et al. [10] have researched on the potential of biogas in Daxing District of Beijing City based on statistical data, and realized the visual expression of biogas potential with GIS software. Cui et al. [11] have surveyed the main crops straw resources in China through literature analysis and field investigation. The results showed that the theoretical amount of main crops straw can reach to 4.33×10^8 t in 2006, and the available amount of energy utilization is about 1.76×10^8 t, which showed a "two high and two low" distribution feature.

However, these researches are mainly focused on regional analysis, and few in whole nation. Liu and Shen [12] have estimated the theoretical reserves of biomass resources in China and showed their geographical distribution by using statistic data, but he failed to point out the amount of biomass resources for energy use quantitatively. In this study, the amount of biomass resources used for energy and their energy utilization potential are estimated by statistical data and the latest research literatures, which is expected to be beneficial to utilize biomass resources effectively, and to arrange the bio-energy industrial development scientifically.

2. Appraise index and methodology

2.1. Appraise index

(1) Theoretical Resources Amount (*TRA*): It refers to the annual total amount of biomass resources in certain area, and it indicates that the largest amount of biomass resources may be obtained in the area.

$$TRA = \sum_{i=1}^{n} P_i \lambda_i \tag{1}$$

P_i is the amount of producing source I and λ_i is the produced coefficient of biomass resource.

(2) Available Resources Amount (*ARA*): It refers to biomass resources that can be obtained by the present collecting approaches and suited for practical uses. It could be estimated as follows.

$$ARA = \sum_{i=1}^{n} TRA_i \eta_i \tag{2}$$

η_i is the collecting coefficient.

(3) Resources Amount for Energy Use (*EURA*): Besides used as energy, biomass resources can be used as fertilizer, feedstuff, mushroom-based material and industrial material. Energy development based on biomass resource should be programmed under the principles of not competing with people for food, not competing with food for land, not competing with livestock for feed and not competing with industry for materials. Available biomass resources used for energy can be calculated as follows.

$$EURA = \sum_{i=1}^{n} ARA_i \beta_i \tag{3}$$

β_i is energy utilization quotiety.

(4) Resources Amount per Capita (*PCR*). According to the source of biomass, the amount per capita of crops straw and poultry-livestock excrement can be estimated on the basis of rural population, and municipal solid waste resources are calculated by urban population. Forest biomass and organic wastewater are determined by industrial scale, having a weak correlation with the population distribution. Therefore, the amount of resources per capita was neglected this study.

(5) Resources Density (*RD*). Resources density means the amount of available biomass resources can be obtained in unit area, and it is an important indicator to determine the development of bio-energy industry.

2.2. Methodology

2.2.1. Potential estimation of energy utilization

There are various methods that convert biomass into energy, which included direct combustion, physic-chemical conversion and biochemical conversion [13]. The output of energy products and their potential acting as substitutes for fossil energy (taking coal as an example) were estimated based on the assumption that biomass resources are utilized by a specific method.

(1) Energy products from biomass conversion are used for heating

$$M_{substitution} = \frac{B \times p \times Q_b \times \eta_b}{Q_c \times \eta_c} \tag{4}$$

$M_{substitution}$ is the substitution for coal consumption (t) and B is the amount of biomass resources (t).

p is the energy product yield, m^3/kg or kg/kg; briquette yield is 0.924 kg/kg,[1] biomass gasification yield is 2.39 m^3/kg [14], biogas from crops straw fermentation yield is 0.3 m^3/kg (TS), biogas from excrement fermentation yield is 0.35 m^3/kg [15], anaerobic fermentation yield of organic wastewater is 0.907 m^3/(kg COD) [12].

$Q_b(Q_c)$ is the calorific value of biomass fuels (coal), kJ/m^3 or kJ/kg, it is defined as follows: crops straw is 12–15 MJ/kg, firewood is 16–18 MJ/kg, household biogas is 20.93 MJ/m^3, industrial biogas is 25.92 MJ/m^3, briquette is 18.83–23.01 MJ/kg, and gasification fuel gas is 5.30–6.43 MJ/m^3.

$\eta_b(\eta_c)$ is the thermal efficiency of biomass fuels (coal), %; defined as follows: stove burning is 15–20%(calculation based on low value terms), boiler burning is 30%, biomass compressing is 45%, gasification heating is 55%, and biogas burning is 55%–60% (calculation based on low value terms).

(2) Energy products from biomass conversion are used for power generation.

$$M_{substituton} = \frac{B \times p_b}{p_c} \quad (5)$$

P_b is the power generation efficiency of biomass, kW h/kg; in small scale gasification power generation system, power generation efficiency ranges from 14% to 20%, biomass consumption per unit power generation ranges from 1.3 kg to 1.8 kg; and in the medium scale system, power generation efficiency ranges from 25% to 35%, biomass consumption per unit power generation is estimated to be 1.1 kg/kW h [16]. Low value term as 1.8 kg/kW h was chose as the basis for calculating in this study.

P_c is the power generation efficiency from fossil fuels, kW h/kg; it is adopted average coal consumption during the power generation process in 2007, and which is 356 gce/kW h [17].

2.2.2. Greenhouse emissions estimation

Biomass energy utilization has important impacts on greenhouse emissions reduction through the following ways. (1) CO_2 in atmosphere is sequestrated by the green plant, and formed carbon sink. (2) CH_4 emissions reduction from anaerobic fermentation of crops straw, weed, poultry and livestock excrement and organic wastewater. (3) CO_2 emission during the biomass burning process acts as carbon sources. (4) CO_2 emissions reduction is realized through the substitution for coal utilization, as biomass resources are used for power generation, central heating and household cooking [18]. As a mutual process between (1) and (3), both were ignored, and the calculation following-up only includes (2) and (4).

(1) Greenhouse gas emissions from the manure management system can be calculated with the methods recommended by "*IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*" [19].

$$C = \sum_i \gamma_i \times P_i \times \frac{44}{12} \quad (6)$$

C_{CH_4} is the greenhouse emission in manure management system, equivalent to $kgCO_2$; γ_i the CH_4 emission coefficient of the livestock, kg a^{-1} $head^{-1}$; P_i is the number of the livestock.

(2) CH_4 emission from industrial wastewater management system. It is measured that CH_4 emitted from sewage treatment plant accounts for 5% of the global emission. And CH_4 emission during the industrial wastewater treatment can be calculated as follows [20].

$$C_{CH_4} = C_{BOD_5} \times 0.22 \times \frac{44}{12} \quad (7)$$

C_{BOD5} is the biochemical oxygen demand (5 days) in wastewater (BOD_5) (kg) and 0.22 is the CH_4 emission efficiency (kg/kg).

(3) CO_2 emission from coal burning is estimated by formulas proposed by Wang [21].

$$C_{coal} = P \times (C_p - C_s) \times C_0 \times \frac{44}{12} \quad (8)$$

C_{coal} is the CO_2 emissions from coal burning, t; P is the coal consumption, t; C_p is the carbon content, %. It is calculated as the calorific value of fuel product and carbon emission coefficient. Calorific value of coal is estimated to be 0.0209 TJ/t, and carbon emission coefficient is considered as 24.26 t/TJ. C_s is the carbon storage in the product, %. And it is defined as the carbon not being emitted or not immediately emitted, and this part of energy is not always estimated. C_0 is the carbon oxidation rate, %. 80% of that in civil use, and 89.9% in agricultural production, 44/12 is the molecular weight ratio of CO_2 to C.

2.3. Data source

Original data used in this study for forest biomass resource estimation are derived from the *Sixth National Forest Resources General Investigation* [22] and web site of *State Forestry Administration, PRC* (http://www.forestry.gov.cn), other data are obtained from China Statistical Yearbook of 2008 [23] and China Agricultural Statistics Report of 2007 [24]. The indicators and parameters mentioned are derived from related articles.

3. Geographic distributions and available amount of biomass resources in China

There are various kinds of biomass resources in China, namely agricultural waste, forestry waste, municipal solid waste, and organic wastewater which associated with the industrial production, agricultural activities and human daily lives.

3.1. Crops straw

Crops straw is the residues after agricultural crop harvest, which is the main byproduct of agriculture production. However, crops straw is not a statistical index but rather a complex unit, therefore we estimated the amount of crops straw by the agricultural crop production which could be found in statistical databases, ratio of residue to grain, collected coefficient and straw utilization structure, etc. in which the key is to determine the ratio of residue to grain. With the development of modern agricultural cultivating technologies and the appearance of high-quality and high-yield technologies, the ratio of residue to grain which could be determined by field tests or empirical formulas progresses gradually. Different ratios of residue to grain are adopted during the process of straw resources estimation [25–27]. Considering the existed estimation methods and the geographic distributions, the estimation of crops straw resource in this study is based on the measured data by Cui et al. [11]. In 2007, the total output of crops including food crops, oil crops, cottons, bastfiber crops, etc. can reach 6.58×10^8 t, and 5.33×10^8 t of crops straw could be produced (Table 1). In addition, many kinds of crops' stubbles should be retained after the harvest, and losses of branches and leaves always happen during the straw collecting and transporting.

[1] According to dry material of biomass, briquette water ratio is estimated ranging from 5% to 10% (in this article, 8% is chose), crops straw water ratio is estimated as 15% and briquette production rate is calculated as $p = (1 - 15\%)/(1 - 8\%)$.

Table 1
Amount of crops straw resources in China in 2007.

Types of crops		Crop output/10^4 t[a]	Ratio of residue to grain	Theoretical crop output/10^4 t	Collection coefficient	Available resources amount (TS = 85%)/10^4 t
Food crops	Rice	18,603.4	0.68	12,650.31	0.78	9867.24
	Wheat	10,929.8	0.73	7978.75	0.76	6063.85
	Corn	15,230.0	1.25	19,037.50	0.95	18,085.63
	Legume crop	1720.1	1.5	2580.15	0.75	1935.11
	Tuber crop	2807.8	1.0	2807.80	0.75	2105.85
	Others	869.1	1.5	1303.65	0.75	977.74
Oil crops	Peanut	1302.8	1.01	1315.83	0.90	1184.25
	Rapeseed	1057.3	1.01	1067.87	0.90	961.09
	Sesame	55.7	1.01	56.26	0.90	50.63
	Others	153	1.01	154.53	0.90	139.08
	Cotton	762.4	5.51	4200.82	0.90	3780.74
	Bastfiber crop	72.8	2	145.60	0.90	131.04
	Total	65,752.4		53,299.08		45,282.24

[a] It is derived from China Statistical Yearbook of 2008 [23].

According to mechanized harvesting level and collection efficiency available amount of straw resources reach 4.53×10^8 t. Apart from 24% of which is used as animal feed and 3% as industrial raw materials [28,29], the rest of which is probably 73% of the total collectable amount can be used as energy feedstock, i.e., 3.31×10^8 t of crops straw with 15% water content can be converted to energy, which is equivalent to 1.42×10^8 tce.

The distributions of crops straw resources have distinguishing geographical diversity, because of different farming patterns which caused by regional natural climate, socio-economic conditions, cultures and traditions. Henan Province and Shandong Province, which locate in the alluvial plain of middle and lower reaches of Yellow River, have advanced agricultural development, and the amount of crops straw resources acted as energy sources exceed 30 million tons per year. Meanwhile, the crops straw resources in Tibet and Qinghai Province are sparser because of the cold weather and undeveloped agricultural system.

The main way of crops straw utilized for energy is to provide fuel gas to satisfy the daily energy consumption in rural areas. Resources per-capita is an important factor to considering in the process of crops straw utilization. It is showed that per-capita quantity of crops straw resources has a manifest gap between the southern and the northern in Fig. 1. The northern areas such as Jilin Province, Heilongjiang Province, Inner Mongolia Autonomous Region and Xinjiang Uygur Autonomous Region have larger quantities of per-capita resources which is above 1 t/people. And southeastern coastal areas, such as Zhejiang Province, Fujian Province, Guangdong Province and Guangxi Province, have large population but lower per-capita resources that are below 300 kg/people.

Resource density which mirrored the concentration intensity of resource distribution is one of the important factors to determine the industrial layout of crops straw utilized for energy. The top three regions with the highest crops straw density are Jilin Province, Liaoning Province and Xinjiang Uygur Autonomous Region, the utmost attentions should be paid on these areas. Secondly, areas such as Shandong Province, Inner Mongolia Autonomous Region, Hebei Province, Shanxi Province, Henan Province and Jiangsu Province etc. have relative high density of straw resources that are easy for collection and utilization. Moreover, as a particular case showed form Fig. 2, Tibet has a high density of straw resources ranging from 3200 kg/hm^2 to 4000 kg/hm^2, but in fact, it has small quantities of total farm, and therefore, the potential of straw utilization is poor.

3.2. Forest biomass

Forest biomass is the wood resources produced in the forestry production, including fuel wood, forestry harvesting residues, wood processing waste, and forest pruning and brunches, etc. [30]. According to the energy generation efficiency and collected coefficient [12,29], the total amount of biomass resources and

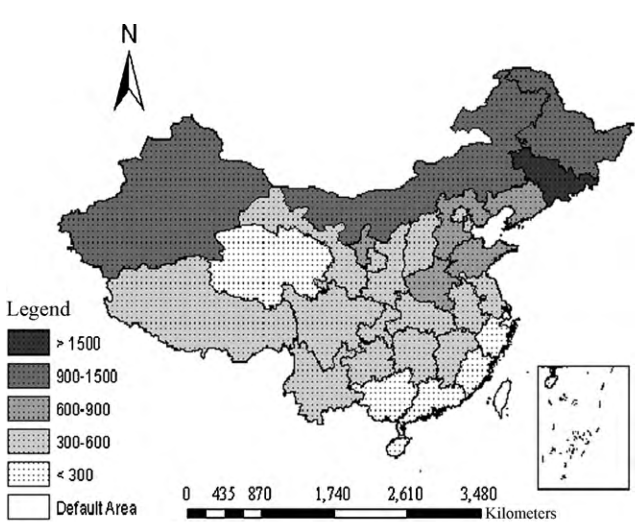

Fig. 1. Per-capita amount of crops straw resources in China (kg/people).

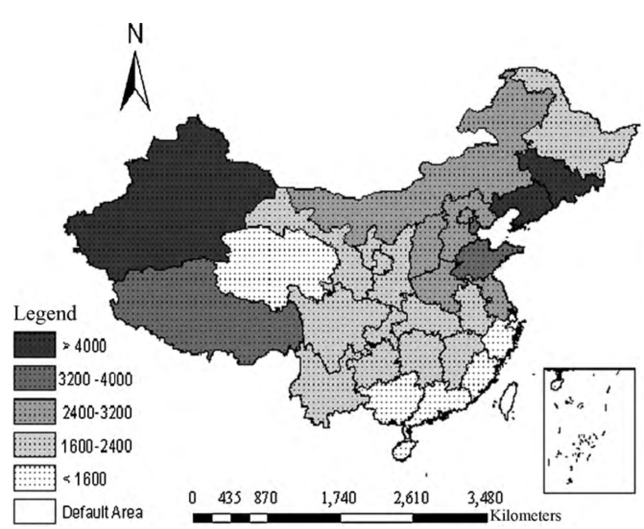

Fig. 2. Density of crops straw resources in China (kg/hm^2).

Table 2
Amount of biomass resources in China.

Resource types		Area[a]/10^4 hm^2	Forestry stock/10^4 m^3	Resource produced rate[b]	Biomass resource yield/10^4 t	Collectable rate	Available biomass resource/10^8 t
Firewood	Firewood forest	303.44	5627	100%	6583.59	100%	6583.59
Logging residue	Timber forest	7862.58	552,241.94	40%	258,449.20	30%	77,534.76
Processing residue	Log production		6399.6	34.4%	8779.94	80%	7023.95
Tending and	Timber forest	7862.58	552,241.94	0.67 t/hm^2	4717.55	30%	1415.26
intermittent cutting	Economic Forest	2139	344,557.9	1 t/hm^2	2139.00		641.70
Total					280,669.28		93,199.27

[a] It is derived from the Sixth National Forest Resources General Investigation.
[b] It is derived from Refs. [12,29].

distribution are estimated on the basis of data of *Sixth National Forest Resources General Investigation*. Theoretically, it is estimated that 2.81×10^9 t of biomass could be obtained during forest producing and felling, and almost 9.32×10^8 t could be collected and utilized (Table 2). If all of the firewood and 50% of other forest biomass resource could be used for energy, the annual amount of forest biomass which could be converted to energy can reach 4.99×10^8 t, equivalent to 2.85×10^8 tce.

It is presented a distinct lateral band in the distribution of biomass resource reserves which could be used for energy (Figs. 3 and 4) in the Southern regions of China, which included Sichuan Province, Yunnan Province, Guizhou Province, Fujian Province, Guangxi Province, Guangdong Province and Hunan Province, it was found with abound forest biomass resource because of large areas for forest planting and warm-wet climate. In the northern regions, which is the secondly areas with rich forest biomass resource included Heilongjiang Province, Jilin Province, Inner Mongolia Autonomous Region and Xingjiang Uygur Autonomous Region, and the amount of forest biomass resource in every province exceed 10 million tons. It is due to the vast territory, sparse population and poor land conditions which are not suitable for agricultural planting, and turned for forest land uses.

In addition, with the demand of eco-environmental protection and the implement of the projects of "*Three North Shelterbelt Forest System*" and "*Returning Farmland to Forestry*", forest land in northern regions increases and biomass resource diversifies gradually. In the central part region of China including Henan Province, Hebei Province, Shanxi Province, Hubei Province, Anhui Province and Shandong Province, have relatively fewer forest lands due to the denser population and the high majority of land used for agricultural planting. Scarce forest biomass resources are found in Tibetan Plateau which includes Tibet, Qinghai Province and Gansu Province. Considering the resource density, it is have higher forest biomass density and convenient to make exploitations in East China. However, taking the total resources into account, we can draw a conclusion that Southeast areas, Southwest areas, Northeast areas and Xinjiang Uygur Autonomous Region are the first choice regions for forest biomass industrial development.

3.3. Poultry and livestock manure

Poultry and livestock manure is a kind of important biomass resource, which is the main feedstock for biogas fermentation. The amount of poultry and livestock manures could be calculated by the breeding cycle, daily excretion, and amount of livestock on hand and livestock has been sold [31,32] (Table 3). It has raised cattle almost of 1.4×10^8 and pigs of 4.9×10^8 in 2007 in China, the total amount of poultry and livestock excretion resource is 3.99×10^9 t and dry weight is 1.201×10^9 t, equivalent to 6.47×10^8 tce. Considering the collected efficiency, the amount of excretion can be used is estimated to be 3.01×10^9 t, equivalent to 4.40×10^8 tce.

There are three ways to utilize poultry and livestock excretion: used for fertilizer, feed and energy. Excretion-based feed is unsuitable to recommend due to the potential security hazards at present. So it is suggested that the all available excrement should be converted to energy, because it can produce biogas during the anaerobic fermentation and also can provide organic fertilizer from the slurry residue. The amount of excrement that could be converted to energy is estimated as 3.01×10^9 t.

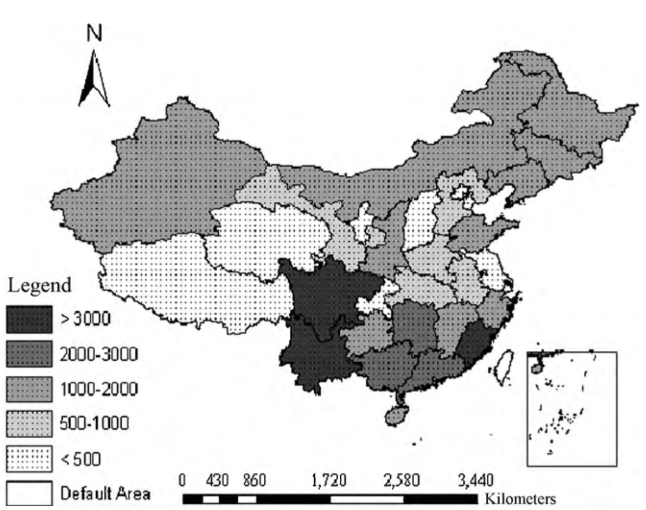

Fig. 3. Amount of forest biomass resources for energy use possibly in China (10^4 t).

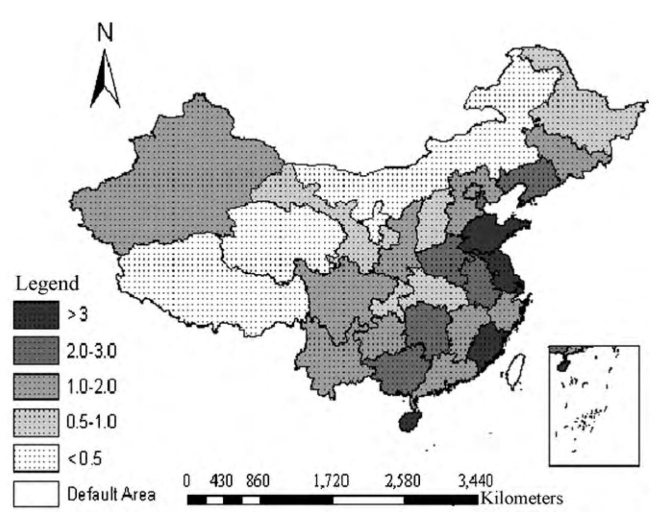

Fig. 4. Distribution density of forest biomass in China (t/hm^2).

Table 3
Amount of livestock excretion resources in China.

	Livestock breeds							
	Cow	Horse	Donkey/Mule	Pig		Chicken	Sheep	Total
				Marketable stock	Standing stock			
Quantity[a]/10^4	13,944.2	719.5	730.6/345.1	68,050.4	49,440.7	731,852.17	36,896.6	
Excretion coefficient	8.2 t/a	5.9 t/a	5.0 t/a	5.3 kg/d	5.3 kg/d	0.15 kg/d	0.87 t/a	
Breeding cycle/day	365	365	365	300	365	55	365	
Amount of waste/10^8 t	11.43	0.43	0.54	10.52	9.56	3.92	3.21	39.91
Collection coefficient[b]	0.60	0.60	0.60	0.90	0.90	0.60	0.60	
Annual usable amount/10^8 t	6.86	0.25	0.32	9.74	8.61	2.35	1.93	30.06
Dry matter content[b]/%	18.00	18.00	18.00	20.00	20.00	80.00	80.0	
Dry biomass of excrement/10^8 t	1.23	0.05	0.06	1.95	1.72	1.88	1.54	8.43
Standard coal coefficient[b]	0.471	0.471	0.471	0.429	0.429	0.643	0.643	
Standard coal equivalent/10^8 t	0.58	0.022	0.027	0.84	0.74	1.21	0.99	4.40

[a] Data is arranged on the basis of China Statistical Yearbook 2008.
[b] Data is derived from Refs. [29,33].

It is indicated in Fig. 5 that the distributions of total livestock manure resources have no significant regional difference in China, However, a marked difference between the East and the West can be found from the resource density distribution (Fig. 6), which may be ascribed to the lower commercialization of livestock feed and serious localization of livestock breeding. In addition, more reasons maybe relate to the difficult collection of excrement in the bulk grazing of Inner Mongolia Autonomous Region, Qinghai Province, and Xinjiang Uygur Autonomous Region. Oppositely, it has a higher excrement collection coefficiency with the dominant stable breeding in Eastern regions of China.

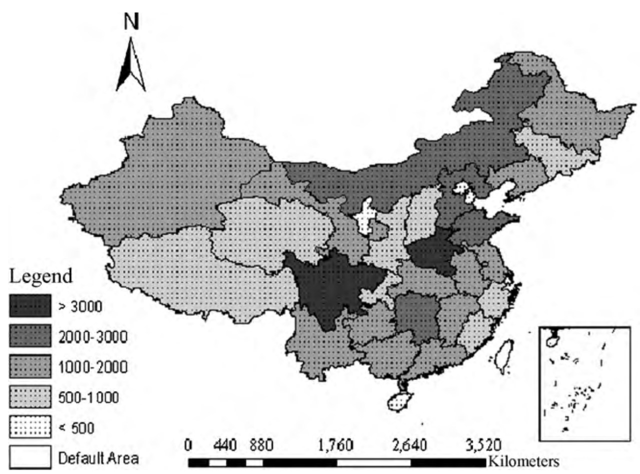

Fig. 5. Amount distribution of poultry and livestock manure resources for energy use possibly in China (10^4 tce).

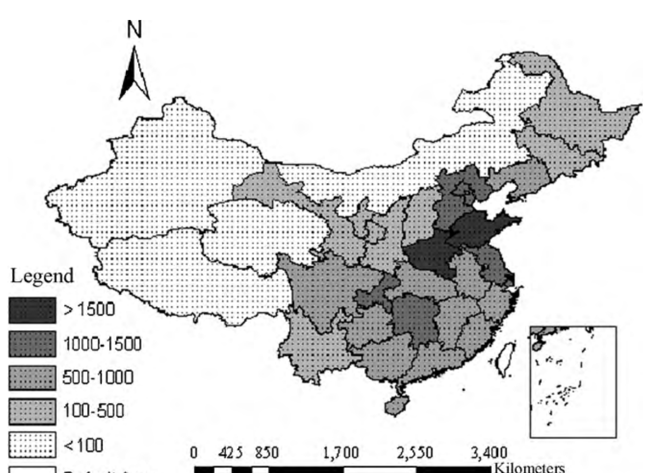

Fig. 6. Distribution density of poultry and livestock manure resources in China (kgce/hm^2).

3.4. Municipal solid waste

Municipal solid waste means the solid waste generated from daily life. By using advanced technologies such as incineration power generation and landfill gas recycle, waste utilization industry will be realized. With the development of society, the waste disposal ways expand from open-air dumping to centralized approaches such as composting, landfill and incineration. According to statistics, the daily waste production per capita reaches to 1.4 kg in big cities, and about 1 kg in small and medium-size cities [34]. By a comprehensive analysis, the daily urban waste emission efficiency is to be estimated as 1.2 kg per capita. In theory, the Chinese municipal solid waste emissions can reach 3.70×10^9 t, equivalent to 5.29×10^8 tce. But due to low utilization rate, the municipal solid waste clearance was only 1.52×10^8 t in 2007, including 7.63×10^7 t of sanitary landfill, 2.50×10^6 t of composting and 1.44×10^7 t of burning [23]. According to collected coefficient of 62%, available municipal solid wastes is estimated to be 9.43×10^7 t, equivalent to 1.35×10^7 tce.

The distribution of available municipal solid wastes is closely allied to urban population and waste collection efficiency. It is showed in Fig. 7 that Guandong Province has the largest quantities of available municipal solid wastes which is consistent with the fact that it is the largest province of urban population in China. Other big cities such as Beijing and Shanghai have the smaller urban population which at the rank of 21st and 16th, respectively. However, with the relatively completed infrastructure, the collection rate reaches 90%, and the rank of available urban solid waste resources increased to 11th and 8th.

3.5. Organic wastewater

Organic wastewater can be divided into two categories, i.e., domestic sewage and industrial waste water. Industrial waste water is mainly defined as the waste water discharged from the production process of alcohol, sugar refining, food, pharmacy, paper making and slaughter. In China, the amount of industrial waste water discharged reach 2.47×10^{10} t in 2007 [23], the available amount is almost 2.22×10^{10} t by the collection coefficient of 90%, and COD discharged is 4.60×10^6 t, equivalent to 3.58×10^6 tce. Domestic sewage is drainage associated with urban residents living, commercial activity and service industry. It

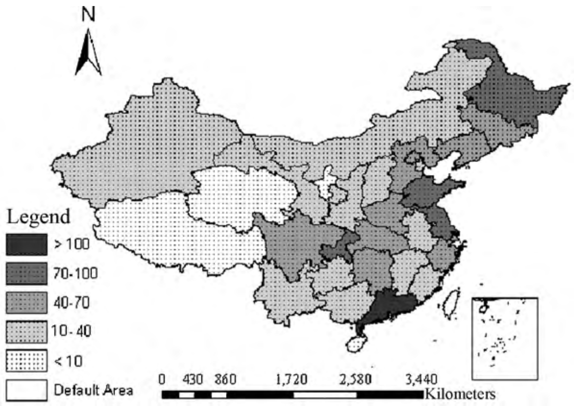

Fig. 7. Amount of municipal waste resources for energy use possibly in China (10^4 tce).

was estimated that amount of domestic sewage reach 3.10×10^{10} t in 2007, COD content is almost 8.71×10^6 t. Calculated by the disposal rate of 42.55% [35], available amount of domestic sewage can reach 1.32×10^{10} t, COD is 3.71×10^6 t, equivalent to 2.88×10^6 tce.

It could be concluded from Fig. 8 that organic wastewater resources are mainly distributed in industrialized areas such as Guangdong Province, Guangxi Province, Hunan Province, Zhejiang Province, Shandong Province, and Sichuan Province, etc. and eco-culturing and anaerobic fermenting by microalgae resource could be implemented based on the wastewater quality and quantity in these areas.

3.6. Total amount of biomass resources in China

From the analysis mentioned above, it is concluded that the biomass resource is rich in China. The theoretical reserve of biomass resource is above 3.02×10^9 tce, the available quantity reach 8.87×10^8 tce, and crops straw, excrement, forest biomass account for 15.90%, 49.62% and 32.13% respectively. Except for arctic-alpine areas and deserts such as Tibet Autonomous Region, Qinghai Province, Gansu Province, Ningxia Province, etc., the distribution of biomass resource is relatively average in China (Fig. 9), each province has different kinds of biomass resource distributed. The areas where biomass resource is available in

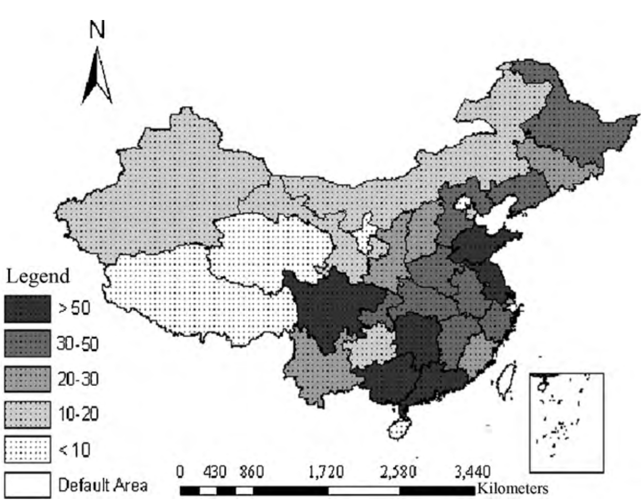

Fig. 8. Amount of organic wastewater resources for energy use possibly in China (10^4 tce).

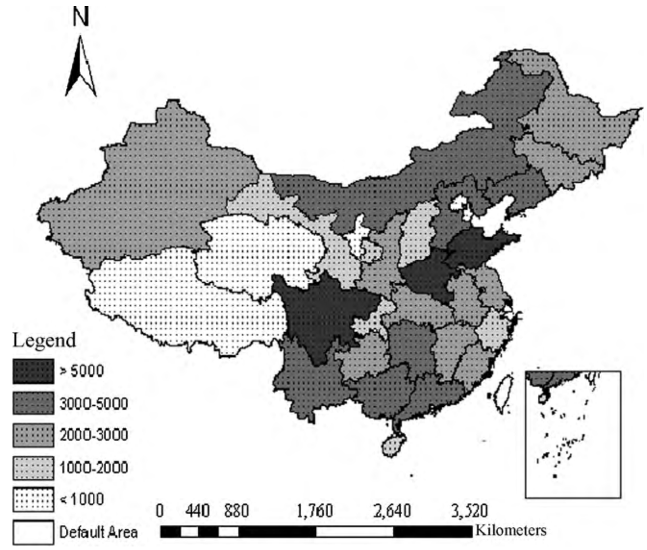

Fig. 9. Amount of biomass resources for energy use possibly in China (10^4 tce).

largest quantity are in Sichuan Province, Shandong Province and Henan Province with an annual output above 50 million tons. Secondly, in the regions including Inner Mongol autonomous region, Heibei Province, Liaoning Province, Hunan Province, Yunnan Province, Guangxi Province, and Guangdong Province, etc., the total amount of resource in each province ranges from 30 million tons to 50 million tons.

According to the available biomass resources per unit area (Fig. 10), an obvious difference could be observed. In Henan Province, Shandong Province, Hebei Province, Liaoning Province, Jiangsu Province, Hunan Province and Fujian Province, etc., it has relative advantage in collecting and utilizing with the high centralization of biomass resource distributed. And in the western regions of China, with the less total resource amount and vast and area, the amount of biomass resource that can be utilized for energy in per unit area is lower than 500 kgce/hm^2.

4. Potential estimation of biomass resource energy utilization in China

The alternative solution of biomass resources acting as substitutes for coal has been proposed on the basis of coal

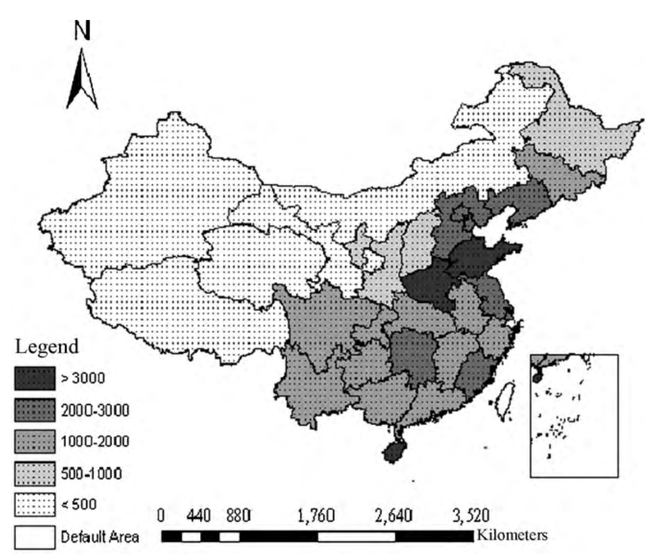

Fig. 10. Density of biomass resources for energy use possibly in China (kgce/hm^2).

Table 4
Type of the coal substituted by biomass resource utilization for energy.

Conversion way	Substituting way and proportion	Note
Stove burning	Coal consumption of living, the proportion is 100%	The efficiency of coal for thermal power plant, industrial boiler and living is 90%, 60% and 30%, respectively
Boiler combustion	Coal for industrial boiler, the proportion is 60%	
Biomass compressing and shaping	Coal for thermal power plant, industrial boiler and living, the proportion are 55%, 39% and 6%, respectively	
Biogas heating	Coal for industry and living, proportion are 80% and 20%, respectively	
Biogas generation	Coal for thermal power plant, proportion is 100%	
Gasification heating	Coal for thermal power plant, industrial boiler and living, the proportion are55%, 39% and 6%, respectively	
Gasification power generation	Coal for thermal power plant, proportion is 100%	

Table 5
Estimation of biomass resource energy potential in China.

Conversion way		Material		Conversion efficiency	Caloric value (kJ/kg)	Utilization efficiency (%)	Amount of coal saved (10^4 t)	CO_2 emissions reduction (10^4 t)	Coal saved per unit material (tce/tce)	CO_2 emissions reduction per unit material (t/tce)
		Category	Resource amount (10^4 t)							
Stove burning		Crops straw	33,056.04	100%	12,572.7	15	9933.34	14,681.47	0.500	1.035
		Firewood	6583.59		15,444.8		1978.37	2924.03	0.376	0.778
Boiler combustion		Crops straw	33,056.04	100%	12,572.7	30	7946.67	13,278.89	0.400	0.936
		Firewood	6583.59		15,444.8		1943.48	3247.55	0.369	0.864
Biomass compressing and shaping		Forest biomass	49,891.43	92%	18,828	45	27,276.92	45,263.87	0.684	1.589
		Crops straw	33,056.04				18,072.58	29,990.00	0.910	2.115
Biogas fermentation	Heating	Crops straw	33,056.04[a]	0.3 m^3/kg	20,934		9272.22	15,135.97	0.467	1.067
		Excrement	84,282.08[b]	0.35 m^3/kg	25.585	55	32,448.60	54,553.55	0.526	1.239
		Wastewater	830.37	0.67 m^3/kg			731.26	1193.71	0.809	1.849
	Power generation	Crops straw	33,056.04	1.25 kW h/m^3	3601.83	–	4056.60	6778.57	0.204	0.478
		Excrement	84,282.08				14,196.26	25,306.41	0.230	0.575
		Wastewater	830.37				591.67	445.39	0.295	0.690
Gasification	Heating	Forest biomass	49,891.43	2.39 m^3/kg	4808	55	22,009.77	36,778.32	0.552	1.291
		Crops straw	33,056.04				14,582.78	24,367.82	0.734	1.718
	Power generation	Forest biomass	49,891.43	0.56 kW h/kg	3601.83	–	10,671.22	17,831.61	0.267	0.626
		Crops straw	33,056.04				7070.32	11,814.50	0.356	0.833

[a] Water content is 15%.
[b] Dry weight of livestock manures.

consumption structure and main uses of energy products under various utilization modes (Table 4), the potential of biomass resource for energy utilization and greenhouse gas emission reduction are estimated by the method of mentioned in Section 2.2.

Among various biomass utilization ways, it can be concluded from Table 5 that biomass compressing and shaping, biomass anaerobic fermentation for heating and biomass gasification for heating have higher energy conversion efficiency, and of which the highest is biomass compressing and shaping. It can substitute 0.910 tce coal consumption by 1tce crops straw resource after it has been compressed and shaped, and the CO_2 emissions reduction reach of 2.115 t. Meanwhile, in the processes of anaerobic fermentation of organic waste water for heating, crops straw gasification for heating, forest biomass compressing, anaerobic fermentation of livestock manure and forest biomass gasification, the substituted amount of coal consumption by 1 tce of biomass resource can be up to 0.809 tce, 0.734 tce, 0.684 tce, 0.526 tce and 0.552 tce, respectively, and the CO_2 emissions reduction can reach 1.849 t, 1.718 t, 1.589 t, 1.239 t and 1.291 t.

If all the available biomass resources are used for compressing, gasification heating or anaerobic fermentation, and 7.66×10^{12} t of briquette, 1.98×10^{12} m^3 of low calorific gas or 3.84×10^{11} m^3 of biogas will be produced, which means 4.53×10^8 t, 3.65×10^8 t or 4.90×10^8 t of coal will be saved, equivalent to 3.24×10^8 tce, 2.61×10^8 tce and 3.50×10^8 tce, that account for 12.19%, 9.84% and 13.16% of the national total amount of energy consuming in 2007. And from the process of biomass utilization, it can reduce 7.53×10^8 t, 6.12×10^8 t or 7.09×10^8 t of CO_2 emission, which is equivalent to 14.84%, 12.06% or13.98% of the CO_2 emissions in 2004 in China.

On the basis of abundant biomass resources and advanced technology, the biomass resource used for energy have prominent potential and markable profit of CO_2 emission reduction. It is contributive to adjust the energy consumption structure, alleviate the shortage of energy supplement, and reduce greenhouse gas emissions. It will also play significant roles in maintaining national energy security and alleviating global warming.

5. Conclusions

As one of the most important parts in resource science, performance evaluation of resource utilization is the basis and prerequisite for effective resource utilization. The biomass resource is abundant in China. Theoretically, it is estimated that predominant biomass resources such as crops straw, poultry and livestock excrement, forest biomass, municipal solid waste and organic wastewater can reach 3.02×10^9 tce, and 8.87×10^8 tce of that could be available and used for energy, which include straw,

excrement, and forest biomass with the proportion of 15.90%, 49.62% and 32.13%, respectively.

In the total resources distribution, except the arctic-alpine areas and deserts such as Tibet Autonomous Region, Qinghai Province, Gansu Province, Ningxia Province, etc., a relative average distribution could be found, and each province has different kinds of biomass resource that are distributed. Meanwhile, about the distribution of biomass resources, a large regional difference with the characteristics of *East dense* and *West sparse* existed. By analyzing and estimating of biomass energy utilization potential, it is showed that higher conversion efficiency and more significant energy-saving potential are found in biomass compressing and shaping, biomass anaerobic fermentation and biomass gasification for heating. If all of the biomass resources are used for compressing, gasification heating or anaerobic fermenting, and 7.66×10^{12} t of briquette, 1.98×10^{12} m^3 of low calorific gas or 3.84×10^{11} m^3 of biogas will be produced, which means 4.53×10^8 t, 3.65×10^8 t or 4.90×10^8 t of coal will be saved, equivalent to 3.24×10^8 tce, 2.61×10^8 tce and 3.50×10^8 tce, and the CO_2 emissions reduction can reach 7.53×10^8 t, 6.12×10^8 t or 7.09×10^8 t, which is equivalent to 14.84%, 12.06% or 13.98% of the CO_2 emissions in 2004 in China.

It plays a significant role to reinforce the research on biomass collection, biomass conversion technologies and equipments, and to enhance the biomass availability for bio-energy industrial development in the process of biomass utilization, the prior strategy and measures should be established based on the current technology level of biomass conversion. Biomass compressing and shaping, crops straw anaerobic fermenting and gasification for heating should be considered as preferred ways of biomass resource for energy utilization, because of the well-developed technologies and the significant of energy-saving potential and greenhouse gas emissions reducing profit.

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